2011 Monitoring Report King County Stormwater Monitoring Under S8.E of the NPDES Phase 1 Municipal Permit WAR04-4501 (Issued February 2007) Targeted Stormwater Management Program Effectiveness Monitoring Roadside Ditch Stormwater Treatment

March 2012

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1.0. EXECUTIVE SUMMARY

This study, implemented in southeast King County, Washington in Puget Lowland eco-region, explores the use of ditch BMPs to promote storage, treatment and infiltration of stormwater within the existing road ditch network. The BMPs were designed to function within the constraints of road engineering and safety standards while incurring the lowest possible installation and maintenance costs. Ditch BMPs were designed to provide stormwater treatment and/or flow control benefits for low to moderate intensity precipitation events, while maintaining ditch capacity and allowing conveyance of peak winter flows to minimize the risk of localized flooding.

Water Quality BMPs were evaluated through measurement of storm flow and laboratory analyses of storm samples collected as flow-weighted composite samples and/or grab samples. Composite samples were analyzed for total suspended solids (TSS), total and dissolved metals, nitrate-nitrite nitrogen, total Kjeldahl nitrogen (TKN), orthophosphate and total phosphorus, and polycyclic aromatic hydrocarbons (PAH). Additionally, grab samples were collected during the 2010 studies for measurement of total petroleum hydrocarbons and fecal coliforms. Measurements of field parameters (dissolved oxygen (DO), pH, conductivity, temperature and turbidity) were also conducted.

Flow Control BMPs were monitored continuously for water flow for the duration of each project. Flow measurements were collected as matching upstream and downstream data sets to see the effects of the Flow Control BMPs on storm flow in the project site ditches.

Water Quality BMP Effectiveness

Beneficial water quality changes were identified through the monitoring program at one or more project sites: statistically significant reductions were observed in TSS, TKN, total metals: arsenic, chromium, copper, lead, nickel, zinc; dissolved metals: copper lead and zinc, PAHs, and turbidity. Hardness increased after treatment at two project sites; increased hardness is considered to be a water quality benefit.

Flow Control BMP Effectiveness

Flow control benefits included fairly uniform reductions in dry season flows that were observed at all Flow Control BMP project sites, suggesting that the BMPs were storing water and/or promoting infiltration during dry season rain events. The BMPs were designed to withstand high wet season flows that were expected to overtop (bypass) the BMPs without doing damage; wet season flows were typically higher in the effluent than in influent due to watershed inputs along the length of the BMP projects. However, the BMPs also functioned to pool storm flow in the ditch and reduce the scouring energy of both wet and dry season flows. This feature makes these BMP designs a suitable alternative for treating scoured ditch sites with high flows.

Recommendations

Further study would be beneficial in determining the applicability of these BMPs for widespread installation. These ditch studies focused on treating sections of ditches with little prior knowledge of pollutant loads and/or storm flow hydrology. Sampling and testing of storm flow in ditches for pollutants prior to BMP installation would increase the certainty that the BMPs would achieve their objectives by targeting ditches that carry a pollutant load that could be effectively addressed by these types of BMPs.

2.0. INTRODUCTION

The Washington State Phase I Municipal Stormwater Permit (Phase I Permit) applies to all entities in Washington State required to have permit coverage under current (Phase I) U.S. Environmental Protection Agency (EPA) and Washington State Department of Ecology (Ecology) stormwater regulations, which includes cities and unincorporated portions of counties whose populations exceed 100,000. The Phase I Permit includes requirements to conduct stormwater-related monitoring in Special Condition 8 (S8). The required monitoring program detailed in S8 includes three components:

- S8.D Stormwater Monitoring
- S8.E Targeted Stormwater Management Program Effectiveness Monitoring
- S8.F Stormwater Treatment and Hydrologic Management Best Management Practice (BMP) Evaluation Monitoring.

Reporting for all three monitoring components is required as part of Special Condition S8.H and S9. These sections require permittees to complete an annual stormwater monitoring report for each component, to be submitted no later than March 31, detailing monitoring that occurred during the previous water year. A water year starts on October 1 and ends on September 30 of the following year.

This report focuses on the NPDES phase 1 permit requirements listed under Section 8, E, Targeted Stormwater Management Program Effectiveness Monitoring. The monitoring that is being conducted to fulfill this section of the permit is designed to answer two distinct questions:

1. Can roadside ditches in rural areas be retrofitted with stormwater best management practices (BMPs) that will improve the water quality of the stormwater conveyed by these ditches.
2. Can roadside ditches in rural areas be retrofitted with stormwater BMPs that will improve the flow hydraulics of the stormwater conveyed by these ditches.

The King County Department of Transportation (KCDOT) maintains an extensive road network and the stormwater drainage system associated with those roads. A significant portion of that drainage system includes drainage ditches located within the road right-of-way that are designed to collect and convey stormwater away from roadways. These drainage ditches also often provide drainage for stormwater runoff originating from properties adjacent to the road right-of-way. It is in King County's interest to manage the stormwater runoff conveyed in its ditches to protect natural resources, infrastructure and to comply with applicable regulatory requirements. Two key components of stormwater management are pollutant treatment and flow control. Stormwater treatment focuses on removal of pollutants that may be picked up by stormwater as it flows over pollution generating surfaces. Flow control seeks to detain storm flow, and minimize erosion within the ditch. Flow control also seeks to promote infiltration to help maintain ground water levels that may contribute to stream base flow in the dry season.

Traditional stormwater management has often relied on the design, installation and operation of stormwater treatment and flow control devices such as stormwater ponds and vaults. These approaches can be very effective at addressing treatment and flow control requirements in recently developed areas. However, they can be resource-intensive, occupy large areas, generally require significant changes to infrastructure and often are absent in older developed areas. They may also require the acquisition of property on which to site the structures. These limitations led King County to consider alternatives to traditional stormwater management approaches. In 2008, the King County Roads Maintenance Section (KCRMS) sought grant funding through the Washington Department of Ecology (Ecology) Stormwater Implementation Grant Program to assist in funding a study to develop affordable and effective Best Management Practice (BMP) designs to address stormwater runoff issues within existing roadside ditches. This report presents the results of this study including the BMP designs, installation process and costs, monitoring of field parameters and storm flow monitoring, and the treatment effects observed through analysis of influent and effluent stormwater samples. Although the BMPs were designed to require minimal maintenance, the period of this report was insufficient to completely evaluate the maintenance costs of these BMPs.

This study focused on developing and testing in-line ditch stormwater treatment and flow control BMP designs intended to be simple, low-cost, and low-maintenance. The BMPs are intended to reduce or remove water quality contaminants, and attenuate and/or infiltrate storm flows. They were designed to fit within existing roadside ditches, requiring no additional land acquisition or impacts to adjacent lands. The designs are intended to be easily modified to conditions such as soil type, ditch gradient, flow regime, and pollutant type(s). The intent is that by providing research on low cost designs, installation, and maintenance of the these BMPs that this will encourage other public and private entities to retrofit multiple areas, treating stormwater locally and creating an aggregate regional decrease in pollutant and water quantity impacts from roadside ditch discharges.

The BMPs designed and tested during this study were intended to capture small storm events and "first flush" conditions from larger events primarily through detention, provide treatment via settling, adsorption and filtration, and increase opportunities for infiltration of stormwater.. BMPs were evaluated by doing paired studies of stormwater influent and effluent with analysis of stormwater samples, collection of field parameters and storm flow monitoring. To preserve the flood protection function of a ditch – allowing high storm flows to pass downstream – it was also important that the BMPs not compromise the capacity of the ditch, nor be damaged by high storm flows

3.0. GOALS AND OBJECTIVES

The goals and objectives of this study include:

- Development, installation and testing of low-cost BMP designs intended to provide a measurable level of stormwater treatment to either reduce pollutant loads or attenuate storm peak hydrographs within existing roadside ditches.

- Generation of a set of stormwater monitoring data consisting of analytical results and storm flow data that have been subject to quality assurance reviews suitable for comparison of stormwater quality and storm hydrographs upstream and downstream of each BMP. The criteria for collecting and reviewing these data are presented in the QAPP.

- Evaluation of the level of effort and costs required to design, install and maintain the BMPs.

- Provide the results of this study to the community through reports, journal articles and group presentations.

4.0. BMP PROJECTS

4.1 Conceptual Designs

Conceptual BMP designs that described the general BMP treatment concept of focusing water quality and flow control treatment within existing roadside ditches were prepared by KCRMS and presented as part of the project grant proposal. These designs borrowed from low-impact development (LID) methods providing a filter medium for treating stormwater pollutants and in-ditch detention methods to address flow control and encourage infiltration of storm flow.

4.2 Site Selection

The goal of the site selection process was to identify potential stormwater dominated ditch study sites where BMPs could be placed and evaluated. There was interest in selecting ditches representing different environmental conditions, pollutant loads and flow regimes. Information about actual pollutant loads in the ditches was limited to superficial knowledge of site conditions – general information about the land use, traffic density, observations of direct road runoff with little shoulder available for treating sheet flow from the roadway, and observations of scour in the ditch. A screening process was developed to include reviews of road, topographic and soils maps, critical areas maps, information from Roads Maintenance crews and field site visits. A checklist was developed to screen and rank potential sites. The selected ditches would need to carry flow in response to storm events well into the dry season. The selected sites were biased towards locations that were thought to carry storm flow at a volume that could be sampled well into the dry season and that were suitable for the long-term installation of monitoring equipment. Ditch sites were rejected if they appeared to have groundwater influence or might be classified as streams. The sites needed enough slope so that the storm flow would not stagnate or become a mosquito nuisance. This process generated a total of 21 potential sites; further screening for permit and engineering /safety constraints resulted in five potential sites being available for the first year study. This review process continued into the second year, with site selection being further informed by experience gained during the first year.

4.3 Water Quality BMP Project Sites

Project locations, installation dates monitoring time frame and project identifiers used in this report are presented in Table 1. Project locations are also mapped as shown in Figure 1. Projects 148 and 136 were installed in June 2009. Information gained during this study led to modifications of the BMP designs for the 2011 water year projects (Projects 192 and OP). The 192 and OP projects were installed late in the dry season of 2010.

Project 148

Project 148 is located in a ditch running along the east shoulder of 148th Ave SE (Figures 2 and 3), a collector – arterial road just south of SE 102 St as shown in Figure 2. The ditch drains an area north of SR 900 and east of 148th Ave SE that is dominated by rural residential properties. The road is crowned, has a with very limited shoulder and stormwater flows directly from the road surface into the ditch. The ditch flows to the north, draining to May Creek. The roadway has a moderate average daily traffic (ADT) volume of approximately 2,000 vehicles and has narrow shoulders on the ditch side of the road. Three water quality BMPs were installed in the spring of 2009 for monitoring during the 2010 water year.

Project 136

Project 136 is located along the north shoulder of SE 136th St, just west of 170th St SE (Figures 4 and 5). This ditch follows the north shoulder of SE 136th St draining an area of neighborhood to the north and east dominated by residential developments at 4 residences per acre. An elementary school is located north of the watershed; a high school is adjacent to the project at SE 136th St and 169th Ave SE. Flow continues north-east through a neighborhood drainage system. SE 136th St is a local road with a moderate average daily traffic (ADT) volume of approximately 1,520 vehicles and is busy with morning and early afternoon school traffic. Four water-quality treatment BMPs were installed in the early summer of 2009 and monitored during the 2010 water year.

Project 192

The Project 192 is located along the south shoulder of Petrovitsky Rd, from a culvert near 17201 SE Petrovitsky Rd downstream to SE 192 Dr (Figure 6). This ditch starts near SE 184th St and flows to the east draining forested land from the Lake Youngs watershed, rural residential properties along the west side of Petrovitsky Rd and direct runoff from the roadway. The ditch drains to Shady Lake downstream of the BMP project. Petrovitsky Rd is a major arterial with a relatively high average daily traffic (ADT) volume of approximately 8,200 vehicles. Six water quality BMPs were installed in late summer of 2010 and monitored during the 2011 water year.

Project OP

Project OP is located along the south shoulder of Petrovitsky Rd just east of the intersection of Petrovitsky Rd and Old Petrovitsky Rd (Figure 7). The ditch flows to the north and receives drainage from Petrovitsky Rd and catch basins along 162 Pl SE that are tiled under Petrovitsky Rd. The watershed along162 Pl SE includes high density residential areas and an elementary school with a storm pond. Petrovitsky Rd is a major arterial with a relatively high average daily traffic (ADT) volume of approximately 8,200 vehicles. Thirteen water quality BMPs were installed in late summer 2010 and monitored during the 2011 water year. This section of ditch was cleaned to native soil just prior to placement of the BMPs.

4.4 Flow Control BMP Project Sites

Project locations, installation dates monitoring time frame and project identifiers used in this report are presented in Table 2. Project locations are also mapped as shown in Figure 1. Four flow control BMP projects were designed, installed and monitored by KCRMS during this study.

Project PET

Project PET was located along the south shoulder of Petrovitsky Rd, across from SE 192 Dr. (Figure 6). This ditch starts near SE184th St and flows to the east, draining forested land from the Lake Youngs watershed, rural residential properties along the west side of Petrovitsky Rd and direct runoff from the roadway. The ditch drains to Shady Lake, downstream from the BMP project. Petrovitsky Rd is a major arterial with a relatively high average daily traffic (ADT) volume of approximately 8,200 vehicles. Five flow control BMPs were installed during the summer of 2009 and monitored during the 2010 water year.

Project 192DN

The 2011 flow control project, Project 192DN was located in the same reach of ditch along the south shoulder of Petrovitsky Rd as the 2010 PET flow control project (Figure 6). Project 192DN consisted of six BMPs that included the five BMPs placed for Project PET with an additional BMP placed between the upstream BMP and the upstream monitoring station. Project 192DN was also located directly downstream from the Project 192 water quality BMP project allowing for a comparison of flow attenuation between the two projects. A conceptual design showing placement of these projects is presented in Figure 8.

Project 276

Project 276 was located along the west shoulder of 276th Ave SE just north of SE 213 St (Figure 9). This ditch starts near SE 216th St and collects runoff from rural residential properties and the paved roadway. The ditch eventually drains to a stream that crosses 276th Ave SE just north of SE 208th St, flowing west toward Issaquah Creek. 276th Ave SE has a relatively high daily traffic volume (ADTV) of approximately 12,700 vehicles. Ten flow control BMPs were placed in July 2009.

Project 276DN

Project 276DN was located along 276th Ave SE just downstream from Project 276 as shown in a conceptual drawing (Figure 10). Thirteen BMPs were placed in December 2010 and monitored for the remainder of the 2011 water year. Placement of Project 276DN just below Project 276 allowed for a second year of monitoring at Project 276 and a direct comparison of low attenuation between the upstream and downstream project.

5.0. ENGINEERING

5.1 Hydrologic Analysis

Each BMP project site was evaluated by the King County Roads Design Unit (KCRDU) for stormwater capacity and to ensure that the 25 year discharge did not exceed the ditch capacity with the BMPs in place. This evaluation included a survey of the selected ditch section, delineation of the watershed boundary, review of soils maps, modeling using KCRTS hydrologic software and completion of hydraulic calculations. Once the peak storm flow for each ditch site was calculated, the water surface elevation in the ditch with the BMP in place was determined through a broad-crested weir calculation. Results from the engineering evaluation for each site are presented in Table 3 (water quality BMP projects) and Table 4 (flow control BMP projects).

5.2 Engineering Designs

Plan drawings for the BMPs can be found in Appendix D.

5.2.1 Water Quality BMP Design

Water Quality BMP structures are based on a rock check dam design, modified with the addition of an internal "treatment cell". Commercially available coarse compost (100% passes through a 3" sieve, maximum particle length of 6 inches, tested in accordance with TMECC test method 02-02-B) was purchased from Cedar Grove Composting[1] and was used as the treatment medium. The compost was mixed by hand with washed gravel at a 2:1 compost to gravel ratio at the project site to increase porosity.

The first year water quality projects (Projects 148 and 136) BMP design plans specified the following:

- A rock check dam structure built from mix of two to four inch and four-to-eight inch crushed rock. BMPs were designed to minimize the erosive effects of flows that were expected to routinely overtop the completed structures. The resulting structures were designed and installed to withstand high winter flows that could otherwise damage both the structure and the ditch.

- An energy dissipation feature was added on the downstream end of each BMP structure consisting of a shallow pit, two feet by four feet and one foot deep filled to the invert level of the ditch with the crushed rock mix. The pit was lined with erosion control fabric prior to placement of the rock.

[1] Cedar Grove Composting, Maple Valley, Washington

- The upstream and downstream check dam slopes are 3H: 1V to conform to road safety design standards and to further minimize erosion from plunging flow.
- The maximum height of the check dam at its crest is one foot, to ensure that the residual water depth does not exceed road safety design standards (two foot maximum depth).
- The compost treatment cell was hand constructed: the mixed rock was placed into the ditch and formed into the check dam shape with a two foot gap in the middle for placement of compost. The gap was lined with erosion control fabric that extended to the upstream and downstream ends of the BMP and filled with coarse compost/washed gravel mix. The ends of the fabric were used to wrap the top of the compost cell and secured with additional rock.

Second year study designs (Projects OP and 192) focused on improving the efficiency of BMP installation through the use of pre-formed compost filled socks that could be purchased commercially, along with minor improvements to the BMP design.

BMPs for the second year of study incorporated the following changes:

- The compost treatment cell for each BMP was purchased as a pre-made “sock” from a commercial vendor, and washed gravel was not included in the compost mix. Applied Organics[2] was selected as the local vendor of Filtrexx®[3] compost socks. The socks used the same grade of coarse compost but were prepared by the vender by blowing the compost into pre-cut lengths of a high-porosity filter fabric sock. The socks can be cut to length as needed. This project specified twelve inch diameter socks six to eight feet in length[4]. The socks were placed so that the ends of the sock were higher on the ditch walls than the expected elevation of the 25 year recurrence storm flows.

- The downstream energy dissipation pad was eliminated from the BMP design. Field review of the first year BMPs showed that the downstream ramp on the check dam was sufficient to dissipate the scouring energy of flows over-topping the BMP, thereby negating the need for an erosion control pad. Eliminating the pad reduced the amount of excavation, reducing costs and saving installation time without affecting BMP performance. Erosion control fabric was pre-placed under the entire length of each planned BMP structure to prevent erosion in the ditch.

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[2] Applied Organics, Redmond, Washington
[3] Filtrexx International, LLC, Grafton, Ohio
[4] The project team, working with the maintenance crew doing the installation elected to have socks prefabricated, filled with treatment medium and delivered to KCRMS. Socks were requested in both six foot and eight foot lengths to fit the expected width of the ditches.

- The socks were placed directly onto the center of the erosion control fabric and staked into place. The socks were moved from a flat-bed trailer to the ditch using choker chains attached to the arm of an excavator and the rock check dam was then constructed around the socks.

- A two layer system of crushed rock was used to form the check dam. The lower layer was composed of two and a half inch minus crushed rock topped with an armor layer of more porous two to four inch rock. The rock layers sandwiched the treatment cell on the upstream and downstream aspects. The armor layer was designed to be stable to at least the 25 year recurrence discharge. Both courses of rock were applied using an excavator and worked into place by hand.

- The upstream and downstream check dam slopes are 3H:1V to conform to road safety design standards and to further minimize erosion from plunging flow.

- The maximum height of the check dam's weir is one foot, to ensure that the residual water depth does not exceed road safety design standards (two foot maximum depth).

- For Project OP, a single 12-inch compost sock was used in each BMP. For the Project 192 two 12-inch socks were deployed, one directly on top of the other and then staked together to increase the height of the compost treatment media in each BMP.

5.2.2. Flow Control BMP Design

The first year flow control projects (Projects PET and 276) BMP design plans used a similar rock check design but placed sand instead of compost in the fabric-wrapped treatment cell.

The second year flow control project designs (Project 276DN) and 192DN) intended to increase construction efficiency by using the compost socks instead of sand wrapped in fabric. Twelve inch socks were used with two stacked one on-top of the other and staked. The check dam was finished using layers of 2 inch minus rock around the base of the socks and 4 to 8 inch rock providing the protective outer ramps of the check dam.

Initial concerns regarding placement of roadside ditch BMPs were as follows:

- Would the structures survive the high winter storm flows intact?

- Would the BMPs contribute to flooding?

- Would the BMPs degrade the ditch by increasing scouring flows downstream of the BMPs?

- Would the BMPs result in damage to the roadway?

- Would there be a measurable treatment effect from BMP monitoring?

The BMPs passed all of these tests, with the exception that Project 136 demonstrated only very limited water quality improvements. The initial designs were reviewed for the 2011 water year projects with a focus on creating an easier BMP installation and addressing some design issues.

The second year flow control BMP projects sought to build on the first year monitoring results and to incorporate economies by installing these BMPs adjacent other projects. The 192DN flow control study incorporated the existing BMPs from the first year flow control study with the addition of one new BMP. This flow control project was located just downstream from the newly installed Project 192 water quality BMP study site. This allowed for monitoring flow at three points – upstream and downstream at the 192 water quality projects; and upstream and downstream of the 192DN flow control project with a comparison of the flow attenuation effects of twelve BMPs between the 192 upstream and 192DN monitoring points (Figure 1).

The 276DN project installed 13 new BMPs using the compost sock design directly downstream from the first year (2010 water year) 276 study. Flow monitoring was done at the original upstream station, a mid-point station that represented the downstream end of the 2010 study and the upstream end of the 2011 water year study and downstream from the thirteen newly installed BMPs (Figure 2).

5.3 BMP Costs

5.3.1 Direct Installation Costs

Installation costs for the water quality and flow control BMP projects are presented in Table 5. The eight projects (four water quality and four flow control projects) consisted of between three and thirteen individual BMPs, treating 100 feet to 400 feet of ditch. Costs for installing the BMPs were well within the initial target cost estimate of $5,000 to $10,000 per BMP project, with the focus on producing a design that would be cost effective, simple to install and maintain and produce measureable water quality or flow control improvements. Total costs for BMP installation at each project ranged from approximately $3,000 to $7,500. The average cost for a single water quality BMP structure was just under $900; the average cost for a flow control structure was $500. The BMP cost, averaged among all projects was $700 per BMP. The most significant driver of variation in costs was the number of BMPs placed wherein the larger projects cost more to install. However, due to fairly fixed mobilization costs, the cost per BMP decreased as the number of BMPs installed increased. Projects with up to six BMPs (148, 136 and 192) were installed in a single day; projects with ten and thirteen BMPs required under a day and a half to complete. The OP water quality BMP project and the 276DN flow control project required installation of the largest number of BMPs at 13 placed for each project. The average BMP cost for these two projects was $587 and $460 respectively.

These costs assume the ditch to be treated is currently meeting road design standards – that the ditch will not require cleaning before placement of BMPs. If the ditch does require cleaning there would be an additional cost for that aspect of the project. However, ditch cleaning would be done by the same equipment and crew as required for the BMP installation, and so additional costs could be minimized. The designs are not complicated; the intent is that once a ditch site has been evaluated for permits, hydrological analysis and design specifics (number and location of each BMP structure), an experienced municipal construction crew should be capable of installing these BMPs with minimal guidance and supervision.

5.3.2 Crew and Equipment

All BMP projects were installed by King County Road Maintenance crews. Each BMP project required an excavator for soil removal and placement of rock, dump trucks for material import and export, utility workers to manually place fabric, create or adjust the rock BMP structure, and flaggers for traffic control and safety.

5.3.3 BMP Materials

BMP construction materials included:

- **Erosion Control Cloth:** Non-woven filter fabric (Geotex 801 Non-woven, purchased as an equivalent to Amoco non-woven #4553 filter fabric) was cut into strips wide and long enough to completely underlie the finished BMP. The fabric was purchased in bulk (15 x 300 feet) and cut into sheets by the utility workers to fit the individual site conditions. The sheets were approximately 3 feet wide by 8 to 10 feet long.

- **Crushed Ledge Rock:**
  - **4 to 8 inch rock** (with or without a mix of 2 to 4 inch rock) up to 1 yard per BMP
  - **2 inch minus rock** up to 0.5 yards per BMP
- **Compost:**
  - First year projects**:** These projects used coarse compost purchased in bulk from Cedar Grove Composting. About a yard was purchased for each BMP. The compost was mixed with washed gravel at a 2 to 1 mix, placed into the BMP using hand tools and wrapped with an erosion control cloth wrapping.
  - Second year projects: These projects used twelve inch diameter Filtrexx® compost socks prepared by Applied Organics of Redmond, Washington. The socks were filled with coarse compost from Cedar Grove Composting; the added porosity intended by the addition of gravel was thought to be minimal and no washed gravel was used in the second year socks. The socks for both the 192 and OP projects were pre-seeded with an erosion grass mix. The socks used at Project 192 included a patented Filtrexx® metals treatment medium.

  - The vendor delivered pre-filled compost socks to the KCRMS maintenance facility in Renton where they were stored for a short period and later taken to the installation site by King County crews. The crews installed the socks at each ditch site location using a choker attached to the bucket of the excavator. The vendor can also fill the socks with compost directly on site.

  - Wooden stakes were used to secure the compost socks in place. Three stakes; one at each end and one in the middle of the sock were used.

5.4 Maintenance

5.4.1 Maintenance Costs

The in-line ditch BMPs are intended to function with minimal maintenance requirements. The primary construction materials are simple: crushed ledge rock that was sized to withstand high winter flows and protect the internal treatment medium. The compost socks were seen as an improvement over the hand-built treatment cells both in creation of the BMP and as an easier item for future replacement. Replacement of the treatment cell would require a backhoe to remove either the sock or compost, and place a new sock in the BMP structure (socks could also be filled with compost on site by the vendor). A utility worker would be required to move and reform the rock check-dam structure. Maintenance issues to date at the BMP project sites have been minimal, requiring only minor repairs to the structure of the rock check dams that form the BMPs and contain the treatment media.

Costs for completely replacing or removing the BMP structures would be similar to the installation costs, requiring an excavator or backhoe to remove the BMP and install a replacement structure. Material costs would be lower, assuming that the existing rock for the check dam could be re-used.

The life-span of this monitoring project has been insufficient to determine the life-time effectiveness of the filter media. However, much of the treatment effects of the BMPs come from reducing the energy of untreated storm flow and so some benefits are expected to continue even after the filtration capacity of the BMP is exhausted

5.4.2 Maintenance Plan

The following recommendations for maintenance of the in-line ditch BMPs are based on observations of the BMPs during the time period of this study. This operation time was insufficient to completely assess the lifespan and full maintenance requirements of these structures.

Recommended annual assessment of BMP project sites:

- Integrity of the BMP structure:
    - Rock check dam structure is intact according to its original design elements and the treatment cell is still present and protected.
    - Visual inspection of the treatment cell to determine if the cell (filter fabric and/or compost sock) is still intact. This may require temporarily moving and replacing some of the rock structure by hand.

  - Treatment cells found to be damaged (compost or other media exposed and/or lost from the BMP) or occluded by sediment should be uncovered and replaced.

- Sediment loading in the BMP forbay:

  - Sediment buildup in excess of approximately one-third of the height of the BMP should be removed.

- Condition of the ditch: The ditch should be inspected for scour, erosion or undercutting that could result from high flows overtopping the BMPs.

- Other concerns in the ditch: Excessive debris, e.g., wind-blow debris such as tree limbs and excessive leaves should be removed as soon as they are reported.

- Vegetation Management:

  - Ditch vegetation can be mowed using roadside mowing equipment provided the operators are aware of the rock BMP structures in the ditch. Coordination with maintenance staff or installation of warning signs may be necessary. Alternatively, hand mowing by utility workers may appropriate. During the first year studies the project sites were hand-mowed by crews using weed-eaters. During the second year studies the ditches were allowed to be mowed by mechanical mowers that were able to work around the BMPs.

Sediment removal at the project BMP sites has been unnecessary to date. Due to the fairly small volume of the BMP forebay, a vacuum flush truck (eductor truck) is recommended for sediment removal

Maintenance issues identified during field inspections for this project recommended some additional rock to be added to two check dams at Project 192 where the rock had been moved by the high winter flows. This site has compost socks; the socks were still intact. The BMPs did not require sediment removal by the end of the monitoring period.

5.5 Design and Permitting Considerations

Permitting review should include a field visit and site evaluation by the permit specialist. Basic surveying is required to establish the ditch profile and cross-section(s). Design aspects, including hydrological analysis, should require about a day's time for a qualified engineer unless a higher level of design plan is deemed necessary by the engineer. These permitting and design considerations should be part of any road drainage project that includes grading or filling activities and are not exclusive to BMP installation. The level of effort in completing these preconstruction elements will vary slightly with the site and the length of ditch targeted for treatment.

5.5.1 Permitting Considerations

Prior to installing BMPs the project sites should be assessed for permit requirements or constraints, including the following: identification and avoidance of critical areas (streams and wetlands); determination of whether or not Army Corps of Engineers permits would be required for placement of fill in waters of the USA; completion of a cultural resources screening and archeological review; compliance with Road Safety and Design Standards. If critical areas are present, federal, state and local government permits may be required. Due to costs associated with some of these permits, it is preferable to avoid these areas where possible until programmatic permits for these types of projects are in place. Permit costs and associated project delays can be minimized by avoiding or minimizing impacts to critical areas. Working within the existing ditch and minimizing sub-surface work will minimize concerns about impacts to archeological and historic cultural resources and right-of-way issues. The permit inspection and review will typically require a minimum of four hours of the permit specialist's time.

5.5.2 Design Considerations

- Level survey of the ditch:
  - Cross-sectional area and side slope of the ditch
  - Profile slope of the ditch
  - Establish/verify right-of-way limits
  - Location and type of existing drainage features (crossings, culverts, etc)
- Hydrological Analysis/Broad-crested weir calculations
  - Delineate watershed on topographic maps
  - Calculate percentage of pervious/impervious watershed
  - Review soils maps for soil classification
  - Run flow model
  - Broad-crested weir calculation will establish the storm recurrence capacity of the ditch with BMPs in place.
  - Map out spacing interval of the BMPs based on slope of the ditch.

A surveyed profile and cross-section of the ditch will establish the basic ditch geometry and the slope of the ditch. Each BMP should project no more than 1 foot above the bottom of the ditch. The crest of a downstream BMP should be at the same elevation as the toe of the next upstream BMP so that water is ponded between BMPs. Using the one-foot height standard for the BMP structure, the survey can be used to establish the distance between BMPs placements and hence the total number of BMPs per site. Other useful information in planning a ditch BMP project includes the location of structures (culverts, etc) that interrupt the ditch, an assessment of the condition of the ditch, and right-of-way location. Survey information will aid in completing a hydraulic analysis to asses the stormwater carrying capacity of the ditch with the BMPs in place.

Temporary erosion and sediment control plans that detail how construction site runoff and erosion will be addressed will be required during project construction activities.

The BMP plans that were developed for this pilot project required review and approval at the 90% design level by Ecology, requiring a greater level of detail than may be needed for many subsequent projects.

6.0. BMP MONITORING

6.1 Monitoring Design

The BMP monitoring design, analytical parameters and quality assurance protocols are detailed in the QAPP (King County, 2008) prepared at the start of this project. Water quality BMP projects were evaluated though analysis of stormwater samples and measurement of field parameters. Both water quality and flow control projects were evaluated through continuous measurement of flow. At the end of the 2010 studies the project QAPP was revised with changes to the monitoring parameters for the 2011 water year projects. Monitoring parameters and the revisions to monitoring are described in Section 6.2 and shown in Tables 6 and 7.

The water quality BMP study was designed as a “before and after” treatment study with data collected from stormwater influent and effluent monitoring sites as paired sample sets. The evaluations included measurement of storm flow, flow-weighted composite samples, grab samples, discrete measurements of field parameters, continuous temperature monitoring and, during selected storm events, continuous turbidity monitoring.

Flow-weighted composite samples were collected to evaluate the event mean concentration (EMC) of analytical parameters for each sampled storm event. Composite sampling criteria established in the project QAPP called for a minimum of twelve constant volume subsamples or aliquots of storm flow collected on a flow-weighted basis to cover a period that represented at least fifty percent of the total storm flow. The aliquots were directed into a single sample container and thoroughly mixed before splitting into separate sample containers for analysis. Collecting composite samples required estimating the expected storm flow (based on forecasted rainfall totals) and appropriate programming of autosamplers staged at the influent and effluent monitoring locations of each BMP project.

> Programming example: a storm forecast of 0.3 inches of rainfall was estimated to produce 10,000 gallons of storm flow at a project site (based on rainfall/flow comparisons). The autosampler might be set to collect a sample every 250 gallons to obtain a flow-weighted composite sample consisting of 40 aliquots. The actual storm flow would be dependant on a number of factors, including the actual rainfall amount, intensity, and soil saturation conditions – all factors that are not known at the time of sample set-up. Difficulties in meeting either the minimum number of aliquots or sampling the minimum duration of the storm arise if the resulting storm flow is significantly different from the estimated storm flow.

Grab samples were collected during 2010 studies for total petroleum hydrocarbons (TPH) and fecal coliform bacteria, parameters that could not be collected using automated equipment. Grab samples are single samples collected by manually dipping sampling containers directly into the storm flow “early” during the storm event.

Discrete measurements – Field parameters were collected by taking single measurements of storm flow parameters for dissolved oxygen (DO), pH, temperature, turbidity, and conductivity.

These measurements were made using hand-held data sondes and were typically collected immediately following collection of grab samples.

Continuous monitoring parameters. Flow was recorded continuously using automated data loggers and primary flow measurement devices at all sites. Temperature was monitored continuously at all water quality project sites. Turbidity was monitored continuously during selected storm events at water quality project sites 148, 192, OP and flow control project sites PET and 192DN

Rainfall, used to evaluate storm flow, was recorded by real-time gages maintained by the King County Hydrologic Information Center (KCHIC) at gages located near each project site. An on-site rain gage was also located at each water quality project site.

6.2 Parameters

6.2.1 Analytical Parameters

Samples were tested for the analytical parameters listed in Tables 6 and 7. Parameters tested for 2010 studies included total suspended solids (TSS), hardness, nitrate-nitrite (nitrogen), total Kjeldahl nitrogen (TKN), ortho-phosphate phosphorus, dissolved metals (arsenic, chromium, cadmium, copper, lead, nickel, selenium, tin and zinc), seventeen polycyclic aromatic hydrocarbons (PAHs) (Table 7), Project locations, installation dates, monitoring time frame and project identifiers used for water quality BMP projects in this report are presented in Table 1. Project locations are also mapped as shown in Figure 1. TPH and fecal coliform bacteria. Parameters were collected as flow-weighted composite samples except for TPH and fecal coliform which were collected as discrete grab samples. The project QAPP was revised for the 2011 studies with the addition of total metals (arsenic, chromium, copper, lead, nickel and zinc), and total phosphorus collected as flow-weighted composite samples. Collection of dissolved cadmium, selenium, and tin, grab sampling for TPH and fecal coliform bacteria and discrete measurements of field parameters were discontinued.

6.2.2 Field Parameters

Field parameters (DO, pH, conductivity, temperature and turbidity), shown in Table 8, were measured as discrete readings using YSI multi-probe sondes during the first year of monitoring at Projects148 and 136. The intent of this monitoring was to evaluate these single-point measurements early during storm events. Examination of the resulting data showed no discernable difference between influent and effluent readings, perhaps due in part to the logistical difficulties in getting to the projects sites during the early portion of storm events. As an alternative method, continuous turbidity was also measured by deploying sondes during select storm events at Project 148 water quality site and Project PET flow control site. The use of sondes was expanded during 2011 monitoring of the 192 and OP water quality project sites.

6.3 Storm Sampling

Each ditch BMP study site was evaluated via the collection of data from twelve flow-weighted composite samples collected as matched influent/effluent pairs (at Project 148, only eleven storms were successfully sampled). The list of storms sampled, including the storm date, laboratory IDs, antecedent dry period, intra-storm dry period, total storm flow, and sampled storm flow are presented in Tables 9, 10, 11 and 12. Storm sampling followed criteria established in the project QAPP as described below:

Wet Season storm sampling criteria: Antecedent dry period of 24 hours, less than a 6 hour intra-storm dry period, storm volume sufficient to produce adequate flow in the ditch, composite sampling representing greater than 50% of the storm hydrograph.

Dry Season storm sampling criteria: Antecedent dry period of 72 hours, less than a 6 hour intra-storm dry period, storm volume sufficient to produce adequate flow in the ditch, composite sampling representing greater than 50% of the storm hydrograph.

Storm Sampling Figures: Storm sampling summary charts were prepared for each sampled storm event. These charts include storm hydrographs with storm flow in gallons, rainfall hyetograph, and timing of sample aliquots for each successful storm event. These charts are presented in Appendix A (Storm Summary Figures).

Field Monitoring Summary Tables: Spreadsheets detailing site monitoring records were kept throughout the project (see Tables B-1 through B-4 Appendix B). These records included storm sampling attempts and routine site visits to audit field monitoring equipment. These tables include the date of field visits, antecedent and mid-storm dry periods, comparison of flume and meter readings, storm start and stop times, total flow, and total rainfall. The comments section was used to document issues with the sampling or operation of the meters. These tables were used as a tool to audit field sampling activities, review the field forms for completeness and errors and to document conditions that resulted in deviations from the QAPP.

6.4 Baseline Flow Monitoring

Pre-project baseline flow monitoring was used to develop the methods and equipment that would be used during the BMP studies and to start developing rainfall/storm flow relationships for use in composite sampling at each location (KCRMS unpublished data). These studies are summarized below.

Baseline Flow data were collected at the following water quality monitoring stations:

- 148UP: October 30th 2008 through June 3rd 2009. A 1.0 foot HS flume (Dawson & Grant 1997) was originally installed at this monitoring station in late October 2008. This flume was destroyed when a car ran off the road during a snow event on January 4th 2009. The HS flume was replaced with an extra-large 60° V trapezoidal flume on January 27th 2009. The trapezoidal flume was removed on June 3rd 2009 and moved approximately ten feet closer to the upstream ditch culvert during BMP installation on June 4th 2009.

- 148DN: A trapezoidal flume (Dawson & Grant 1997) was installed on February 19th 2009. A site visit on February 26th 2009 found that the meter was set two hours late and was adjusted appropriately (flow peaks for this time period are off by two hours). During the baseline flow monitoring period, some flow was observed leaking around the flume at the ditch backslope. Therefore, this flume was removed on June 3rd 2009, prior to installation of BMPs on June 4th 2009, and the ditch backslope was re-built. The flume was replaced in the same location after BMP installation and ditch repair; the repaired ditch backslope prevented the loss of flow around the flume.

- 136UP**:** Baseline flow data were collected using a Thel-Mar weir from March 3rd 2009 until BMPs were installed on June 11th 2009.

- 136DN: Baseline flow data were collected using a Thel-Mar weir from March 23rd 2009 until BMPs were installed on June 11th 2009.

- PET UP Baseline data were collected from November 20th 2008 until January 30th 2009 using a 1.0 foot HS flume and Isco bubble meter. Additional baseline data were collected from March 31st 2009 into June 2009 using a Campbell Scientific® data logger and pressure transducer. Monitoring was continued into June 2009 until the ditch was dry.

- PETDN: Baseline data were collected from November 20th 2008 until January 27th 2009 using a 1.0 foot HS flume and Isco bubble meter. No baseline data were collected from January 28th until March 31st 2009, at which time a Campbell Scientific® data logger and pressure transducer were installed at the site. Monitoring was continued into June 2009 until the ditch was dry. The downstream flume was moved about 100 feet father downstream to a point below the last BMP after BMPs were installed on June 30th 2009.

Experience with baseline flow monitoring was used to guide development of the BMP monitoring protocols used in subsequent studies.

6.5 BMP Flow and Rainfall Monitoring

6.5.1 Flow Monitoring

Flow was monitored using extra-large 60°V trapezoidal flumes (Dawson & Grant 1997) installed in the ditches at the 148, 192 and OP project sites. At the 136 site, Thel-Mar weirs were installed in existing culverts just upstream and downstream of the BMP installations.

Water Quality BMP Projects:

Continuous paired flow monitoring records for water quality BMP projects include:

Project 148 flow monitoring records from June 17th 2009 through September 30th 2010.

Project 136 flow monitoring records from August 11 2009 through September 1st 2010.

Project 192 flow monitoring records from October 1st 2010 through September 30th 2011.

Project OP flow monitoring records from September 3rd 2010 through September 30th 2011.

Water Quality BMP Projects

Continuous paired flow monitoring records for Flow BMP projects include:

Project PET flow monitoring records from August 10th 2009 through September 29th 2010.

Project 192DN flow monitoring records from September 30th 2010 through September 26th 2011 (a period of record is missing from October 25th 2010 to November 4th 2010 due to instrument malfunction).

Project 276 flow monitoring records from August 10th 2009 through September 28th 2011 and October 1st 2010 through September 28th 2011

Project 276DN flow monitoring records from December 16th 2010 through September 28th 2011.

6.5.2 Rainfall Monitoring

Project rain gages are telemeter equipped gages with real-time records available online, operated by the KCHIC. Historical and real-time rainfall records in increments of 15 minutes, one hour, daily, and monthly are available at: http://green.kingcounty.gov/WLR/Waterres/hydrology/GaugeMap.aspx?TabDefault=Map.

The project rain gage for the 148 and 136 projects was 31UN – Renton Roads rain gage. The 31UN gage has been in operation at this location since October 10th 2000. Project 148 is two and a half miles east-northeast of the 31UN gage, and Project 136 is just over two miles east of the 31UN gage.

The project rain gage for the 192 and OP projects was 31Y2 - Fairwood rain gage. The 31Y2 real-time rain gage has been at this location since October 16th 2009, when it replaced a non-telemeter equipped gage (31Y) that had been in operation since October 1st 1994. Both the OP and 192 projects are approximately one-half mile east-southeast of the 31Y2 rain gage.

7.0. BMP WATER QUALITY RESULTS

7.1 Statistical Analysis of Water Quality Analytical Data

7.1.1 Hypothesis Testing

The BMP study was designed as a "before and after" treatment study. The goal of the study was to create paired sample sets of influent vs. effluent stormwater data that would be evaluated to determine if a statistically significant difference could be identified and if this difference indicated improved downstream water quality. Hypothesis testing (t-tests) were run to determine if the differences in the mean values of the data sets were significant.

Improvement to stormwater effluent quality were assessed as reductions in the event mean concentration of each analytical parameter measured in flow weighted composite samples. This analysis was also performed on grab samples. The reductions are described as BMP percent efficiency calculated as:

$$\frac{\textbf{Influent Value} - \textbf{Effluent Value}}{\textbf{Influent Value}} \times 100$$

Results of the hypothesis tests, along with mean reduction or BMP efficiencies for data sets with values all reported above the laboratory method detection limit (MDL) are presented in Table 13. Mean percent efficiency values and confidence intervals (CIs) for those reductions were calculated using bootstrapping techniques at a 95 percent CI and are included in Table 13. Hypothesis testing and bootstrapping techniques used for this analysis are described below.

7.1.1.1 Non-parametric t-test Evaluation

The function of each BMP project was evaluated by testing the null hypothesis that there is no statistically significant difference between the means of influent vs. effluent data sets (and, therefore, the BMPs have no effect on water quality). This hypothesis was rejected at a 95% CI when a paired sample test resulted in a unitless p value of less than 0.05. The Wilcoxon signed rank test, a two sided test for non-parametric paired samples, was selected to evaluate the BMP data. A Student's t-test was not deemed suitable for testing these data because the Student t-test requires a normal or Gaussian distribution of data around a sample mean. The data sets collected during this study do not follow a normal distribution. This is typical of environmental data, especially when data sets are small (less than 20 data points per test). The assumption of non-normality was evaluated on TSS data using a Kolmogorov-Smirnov (KS) test. The KS test reported that data for TSS was unlikely to follow a normal distribution, although this data set was consistent with a log-normal distribution. The data sets could be evaluated using a t-test on data transformed to log-normal values but transformed results cannot be easily un-transformed. An alternative was to use a non-parametric test that does not rely on the assumption that the data are drawn from a given probability distribution.

The Wilcoxon test does not rely on the sample distribution, but computes the difference between sets of paired samples and analyzes the differences. This test was suitable for evaluating all paired sample data collected during this study regardless of the distribution. In addition to computing a p value at a 95% CI, the test computed an estimated mean of the difference between the influent and effluent values and calculated the upper and lower CIs of the difference. The p value, estimated median, CI and the upper and lower values for the CI are presented in Table 13. The estimated median and CI results have the same units as the analytical test results. Negative values for the estimated mean and CIs show the parameter values increasing in effluent samples collected downstream of the BMPs. The Wilcoxon Signed Rank test computations were accomplished using Minitab® software and a Minitab® macro for the Wilcoxon signed rank test[5].

7.1.1.2 Bootstrapped Mean Efficiency and Confidence Intervals

Mean percent efficiency values for each parameter were calculated using a "bootstrapping evaluation". The bootstrapping process estimates the sampling distribution of a data set and computes nonparametric CIs on the mean and median through multiple iterations of a statistical re-sampling of the data as shown in Figure 11. A Minitab® bootstrap macro was used to run 1,000 re-sampling iterations to produce the bootstrapped means and CIs for percent efficiency values for each parameter[6]. One thousand bootstrap iterations were selected as a sufficiently large number to calculate a reasonable mean value; increasing the number of iterations over this amount was felt to produce a negligible increase in the accuracy of the mean.

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[5] Wilcoxon Signed Rank Test for Paired Data macro downloaded at http://www.minitab.com/en-US/support/macros/view-macro.aspx?action=display&cat=non
[6] Bootstrap Macro downloaded at http://www.minitab.com/en-US/support/macros/default.aspx?q=bootstrap&collection=Macros

7.1.1.3 Data Sets with Non-detected Values

Data sets with non-detects (i.e., results reported as less than the MDL) occurred for dissolved lead, chromium, cadmium, selenium and tin, orthophosphate phosphorus, TPH and fecal coliform. Non-detected data are considered left-censored; the <MDL values cannot be directly presented but are not zero. In order to test the null hypothesis for data sets with less than 90% non-detects (dissolved lead and chromium, orthophosphate phosphorus and fecal coliform) a substitution of ½ MDL was made. While ½ MDL does not represent the true value of those test results it was considered to be a suitable surrogate for use in comparing influent to effluent results. The Wilcoxon signed rank test was then run on the data sets with substitutions. Data sets with greater than 90% of results reported as <MDL (dissolved cadmium, selenium and tin and TPH) could not be evaluated through these methods, and were not further evaluated. Results of hypothesis testing on data sets with non-detects are presented in Table 14.

7.1.2 Descriptive Statistics

Descriptive statistics calculated for data sets included the number of tests, mean, standard error of the mean, standard deviation, minimum, 25th percentile, median, 75th percentile, maximum, inter-quartile range (IQR) and skewness. Minitab® software was used to calculate these statistics on datasets without non-detects. Results are presented in Table 15.

Descriptive statistics for data sets that included non-detects that represented less than 90% of the data were calculated using the Minitab® macro KMSTATS v. 1.8[7]. This macro uses the Kaplan-Meier method for computing descriptive statistics for left-censored data. The macro “flips” the data to a right-censored format then computes the statistics and "unflips" the resulting statistics back into their original units. It uses the Efron bias correction when the lowest value in the data set is censored. The number of tests, mean, standard error of the mean, standard deviation, 25 percentile, median, 75th percentile and 90th percentile are presented in Table 16.

7.1.3 Graphical Analysis using Box Plot Figures

Box plot graphics allow for a visual comparison of data sets. For each parameter the influent/effluent sample pairs collected at each BMP project site are displayed in a single graphic. This allows for viewing the treatment effects from multiple study sites simultaneously.

The box plot graphics, as demonstrated in Figure 13, consist of a ‘box’ drawn around the 25th and 75th percentile values of a single data set, defining the IQR and enclosing fifty percent of

[7] Helsel, D.R., 2005, Nondetects And Data Analysis, Wiley and Sons, 252 p.
KMSTATS v 1.8 Copyright (c) 2004-2009 by Dennis R. Helsel

values from the set. Horizontal lines or ‘whiskers’ above and below the box represent the minimum and maximum values within 1.5 times the IQR. The median value is shown as a bold horizontal line at the narrowest part or waist of the box. If the median is not centered vertically it shows the direction of sample skewness and indicates that the data sets have a non-normal distribution. Outliers – data points that extend more than 1.5 times the inter-quartile range are shown as small circles not connected to the box.

Box plot graphics for each analytical parameter are presented in Figures 14 through 33. Plots for data sets that included non-detected results (dissolved lead, chromium, orthophosphate phosphorus, and fecal coliform) at less than 90% of the data set were created by first substituting ½ the MDL for non-detected values. No plots were created for data sets with greater than 90% non-detected values (cadmium, selenium tin, and TPH).

7.2 Summary of Water Quality Results

7.2.1 Laboratory Analytical Data

Laboratory analytical results of influent vs. effluent stormwater samples collected at the four Water Quality BMP projects are presented in this section. Analytical results are presented in Tables 17, 18, 19 and 20. A summary of the mean BMP efficiencies for parameters with measured treatment effects is provided in Figure 12. Evaluation of these data suggests improvements in the following water quality parameters at one or more BMP project sites:

- Decreased TSS
- Decreased TKN
- Decreased total metals: arsenic, chromium, copper, lead, nickel, zinc
- Decreased dissolved metals: lead, nickel and zinc
- Decreased PAH was measured as the sum of the results from the seventeen PAH parameters tested for each sample in Table 7.
- Increased hardness (increased hardness is considered to be a water quality benefit)
- Decreased turbidity, monitored as continuous turbidity during targeted storm events, was seen at Projects 148, 192 and OP

Hypothesis testing (t-tests) (described in Section 7.1. Statistical Analysis), was done to determine if the observed reductions were statistically significant. Results of the hypothesis testing, along with mean reductions or BMP efficiencies are presented in Tables 13 through 16.

A statistical technique known as “bootstrapping” (discussed further under Section 7.1) was used to compute mean efficiency values along with CI values. The CIs are a range around a measurement that conveys precision of the measurement. Mean percent efficiency values calculated using bootstrapping techniques are also reviewed in Section 7.1.

Laboratory analytical results varied between project sites and the variance between tests at some sites is greater than others. In particular, water quality improvements were not seen at Project 136 where BMP effluent test results were typically higher than influent results. This is thought to be due to difficulties with collecting representative samples in ditches that carry significantly more water than the BMPs were designed to treat, along with the effects of watershed and roadway inputs into the ditch between the influent and effluent measuring stations. Outliers (values greater than 1.5 times the IQR of the data set) are present in most data sets; outliers add to the skew of the data set. The variability of the data and presence of outliers is likely due to uncontrollable variables inherent in testing BMPs in existing ditches (soil saturation, organic and inorganic debris and vegetation, and lack of an exclusive storm flow input location, just to name a few), moving test sites to different locations and watersheds (as opposed to testing different BMP designs in a single ditch), and the intrinsic difficulties with collecting flow-weighted composite samples based on forecasted rainfall amounts with variations in storm volume, intensity and duration, and a wide range of antecedent conditions.

Graphical presentations of BMP treatment effects are presented in Figures 14 through 33 (TSS, presented in Figure 14A, is also presented as a detail in Figure 14B). A box plot comparison of influent and effluent flows measured during sampling events is presented in Figure 34. This comparison shows that flows were often higher downstream during sampling events, but is not representative of the dry season flow regime at these sites.

The treatment percent efficiencies for parameters showing water quality improvement (i.e., the null hypothesis was rejected and pollutant presence in paired sample sets was reduced in effluent samples) are listed below.

TSS

- Project 148: TSS was reduced in 10 out of 11 sample pairs with a mean percent reduction of 44.6%. The upper and lower 95% CI values for the percent reduction ranged from 23.7% to 61.6%.

- Project 192: TSS was reduced in 9 out of 12 sample pairs with a mean percent reduction of 13.1%. The upper and lower 95% CIs of the percent reduction ranged from -21.3% (TSS was higher downstream in some cases) to 40.4%.

- Project OP: TSS was reduced in 9 out of 12 sample pairs with a mean percent reduction of 37.7%. The upper and lower 95% CIs of the percent reduction ranged from 11.3% to 60.4%

TKN

- Project 192: TKN was reduced in 10 out of 12 sample pairs with a mean percent reduction of 12.9%. The upper and lower 95% CIs of the percent reduction ranged from 4.0% to 20.6%.

- Project OP: TKN was reduced in 10 out of 12 sample pairs with a mean percent reduction of 14.2%. The upper and lower 95% CIs of the percent reduction ranged from -4.9% (TKN was higher downstream) to 28.8%.

Arsenic, total

- Project 192: total arsenic was reduced in 10 out of 12 sample pairs with a mean percent reduction of 17.1%. The upper and lower 95% CIs of the percent reduction ranged from 2.3% to 28.5%.

- Project OP: total arsenic was reduced in 10 out of 12 sample pairs with a mean percent reduction of 14.2%. The upper and lower 95% CIs of the percent reduction ranged from 13.0% to 37.9%

Chromium, total

- Project 192: total chromium was reduced in 11 out of 12 sample pairs with a mean percent reduction of 23.2%. The upper and lower 95% CIs of the percent reduction ranged from 14.1% to 31.8%.

- Project OP: total chromium was reduced in 11 out of 12 sample pairs. However, the mean percent reduction was -5.1% indicating an overall increase in total chromium in effluent samples. Hypothesis testing calculated p value at a 94.5 CI of 0.065 and the null hypothesis could not be rejected. Examination of the data showed that effluent chromium was reduced in all but one sample pair and the data set was skewed by outliers. The upper and lower 95% CIs of the reduction ranged from -85.4% (total chromium was higher downstream) to 44.9%.

Copper, total

- Project 192: total copper was reduced in 10 out of 12 sample pairs with a mean percent reduction of 7.9%. The upper and lower 95% CIs of the percent reduction ranged from 3.2% to 20.6%.

- Project OP: total copper was reduced in 10 out of 12 sample pairs with a mean percent reduction of 28.6%. The upper and lower 95% CIs of the percent reduction ranged from 14.4% to 44.1%.

Copper, dissolved

- Project 192: dissolved copper was reduced in 9 out of 12 sample pairs with a mean percent reduction of 15.1%. Data includes one upstream outlier. The upper and lower 95% CIs of the percent reduction ranged from 3.3% to 29.7%. The hypothesis test resulted in a p value of 0.053. The cutoff for rejecting the null hypothesis that there is no difference in influent and effluent sample sets at a 95% CI is a p value 0.05. The result for dissolved copper at Project 192 is right at this value. The box plot comparison indicates a small reduction in dissolved copper at this project site.

- **Lead, total**

- Project 192: total lead was reduced in 11 out of 12 sample pairs with a mean percent reduction of 27.2%. The upper and lower 95% CIs of the percent reduction ranged from 14.9% to 39.2%.

- Project OP: total lead was reduced in 10 out of 12 sample pairs with a mean percent reduction of 33.7%. The upper and lower 95% CIs of the percent reduction ranged from 2.4% to 59.2%.

Lead, dissolved

- Project 192: dissolved lead was reduced in 8 out of 12 sample pairs with a mean percent reduction of 24.8%. This data set included non-detected values; ½ of the MDL was used as a surrogate for the non-detected results[8]. The upper and lower 95% CIs of the percent reduction ranged from 10.4% to 40.2%.

Nickel, total

- Project 192: total nickel was reduced in 11 out of 12 sample pairs with a mean percent reduction of 18.9%. The upper and lower 95% CIs of the percent reduction ranged from 9.2% to 27.7%.

- Project OP: total nickel was reduced in 11 out of 12 sample pairs with a mean percent reduction of 10.5%. The upper and lower 95% CIs of the percent reduction ranged from -36.8% to 41.3% (nickel was higher downstream).

Nickel, dissolved

- Project 192: dissolved nickel was reduced in 9 out of 12 sample pairs with a mean percent reduction of 7.8%. The upper and lower 95% CIs of the percent reduction ranged from 0.9% to 15.0%.

Zinc, total

- Project 192: total zinc was reduced in 9 out of 12 sample pairs with a mean percent reduction of 17.6%. The upper and lower 95% CIs of the percent reduction ranged from 4.0% to 34.7%.

Zinc, dissolved

- Project 148: dissolved zinc was reduced in 9 out of 11 sample pairs with a mean percent reduction of 20.5%. The upper and lower 95% CI values for the percent reduction ranged from 2.2% to 38.9%.

[8] See Section 5.2.1.3 for a description of statistical analysis of data sets with non-detects

- Project OP: dissolved zinc was reduced in 11 out of 12 sample pairs with a mean percent reduction of 16.1%. The upper and lower 95% CIs of the percent reduction ranged from -27.0 % (zinc was higher downstream) to 41.9%

Hardness (increased hardness was evaluated as a water quality benefit)

- Project 148: hardness increased in 11 out of 11 sample pairs with a mean percent increase of 57.0%. The upper and lower 95% CI values for the percent increase ranged from 29.2% to 92.2%

- Project 136: hardness increased in 10 out of 12 sample pairs with a mean percent increase of 8.6%. upper and lower 95% CI values for the percent increase ranged from -1.3 (hardness was lower downstream) to 17.8%.

PAH

PAH detection results were typically very low, with most results below the reporting limit of 0.1 ug/L. Typically only a few PAHs from the 17 PAH parameters analyzed (Table 7) were detected. However, when taken as a sum of all detected PAHs the results at Projects 148, 192, and OP were found to be reduced in BMP effluent samples.

- Project 148: total PAH was reduced in 11 out of 11 sample pairs with a mean percent reduction of 63.1 percent. The upper and lower 95% CI values for the percent reduction ranged from 50.6% to 75.7%.

- Project 192: total PAH was reduced in 7 out of 12 sample pairs with a mean percent reduction of 21.3%. The upper and lower 95% CIs of the percent reduction ranged from 6.5% to 38.4%.

- Project OP: total PAH was reduced in 12 out of 12 sample pairs with a mean percent reduction of 43.5%. The upper and lower 95% CIs of the reduction percent ranged from 28.0 % to 58.1% .

7.3 Field Parameters

Discrete Measurements

Results from monitoring discrete measurements of water quality parameters DO, pH, temperature, turbidity and conductivity are presented in Table 21. This monitoring did not find any significant differences between influent and effluent measurements. However, these observations from single-point sampling differed from the results obtained by continuous monitoring for turbidity (described below) where data sondes were left in place through entire storm events and where an effect of the BMPs on turbidity was observed.

Continuous Turbidity Measurement

Turbidity, monitored using continuous recording data sondes set to log turbidity values in ten minute increments during selected storms, demonstrated that turbidity values were typically lower in BMP effluent. Monitoring results including average and maximum turbidity during the monitoring period for Project 192 are summarized in Table 22, results for Project OP are summarized in Table 23. At Project 192, turbidity monitoring included placement of turbidity sensors at the effluent monitoring site of Project 192DN (the flow control BMP project located directly downstream). Some continuous turbidity monitoring was also done at the 2010 PET flow control study. These results are summarized in Table 24. Figure 35 demonstrates typical results obtained during continuous turbidity monitoring during a storm event at Project OP. Box plot comparisons of mean and maximum turbidity results are presented in Figures 36 through 39.

Continuous Temperature Measurement

Temperature was monitored using continuously recording data-loggers at all water quality BMP project sites. Results from continuous temperature monitoring were summarized as average daily temperature. Periods where no flow was recorded in the ditch were deleted from the data set. The results are shown graphically as box plot comparisons in Figure 40. No significant difference was observed between influent and effluent temperature.

7.4 Flow

Figure 41 demonstrates the relationship between influent and effluent flows at water quality BMP projects during sampled storm events. Storm flow monitored during the wet season and hence a majority of sampled events, showed higher flow in the BMP effluent than at influent monitoring stations due to watershed inputs along the length of the BMP projects. In contrast, a reduction in effluent flows was seen at most BMP project sites during the dry season, particularly in the July to September time frame as shown in Figure 41. Storm flow reductions at water quality BMP project sites were most significant at Project OP which contained the greatest number of BMPs (thirteen BMPs). Comparisons between upstream and downstream total monthly flows for Project OP are presented in Table 25, and graphically in Figures 42 and 43.

8.0. FLOW CONTROL RESULTS

Effluent flow was typically found to be reduced relative to influent flow during the mid to late dry season months (July through early October). Water quality and flow control BMPs were built for different purposes, but function in a similar fashion to treat flow by detaining water, decreasing flow energy, and increasing opportunities for infiltration. Projects with more BMPs (Flow Control Projects 276 and 276DN and water quality Project OP) showed a greater decrease in effluent flow. In 2011, locating later projects immediately adjacent to existing projects (Project 276DN was located immediately downstream of Project 276 and Project 192DN was located immediately downstream of Project 192) allowed for direct comparison of the effects of increasing the number of BMPs on flow. Not unexpectedly, most projects showed higher effluent flows during the wet season when storm flows are highest and the watershed soils are typically saturated.

Typical dry season flow attenuation effects are presented in Tables 26 and 27. Total monthly flows are presented in Figures 44 through 47. Table 26 and Figures 44 and 45 present the results from combined flow monitoring at water quality BMP project 192 and flow control project 192DN. As demonstrated in these charts, the reduction in flow increases with the increasing number of BMPs. A similar comparison showing significant dry-season flow reduction was also seen at Projects 276 and 276DN (Table 27 and Figures 44 and 45).

The combined Projects 276 (ten BMPs) and 276DN (13 BMPs) downstream of Project 276 demonstrated flow reductions at greater than 10 percent during the months of June through September 2011. In June, influent flows of 675,000 gallons were reduced by almost 23 percent. In July and August, influent flows averaged approximately 30,000 gallons each month but were reduced by almost 100 percent. During this time period the majority of the flow reduction was seen within the upper project, Project 276. September demonstrated a reduction in Flows monitored in Project 276, but an increased in effluent flows at Project 276DN, possibly due to watershed input along the length of the downstream project.

Results at the combined water quality Project 192 (6 BMPs) and flow control Project 192DN (6 BMPs) downstream of Project 192 was similar, with effluent flow reductions seen during the dry season months of July, August and September 2011. Additional flow reductions were seen during October at Project 192DN and November 2010. In November, a 1 percent flow reduction was observed between 192UP and 192M, while a 20 percent reduction in flow was observed between 192M and 192DN.

9.0. SUMMARY AND CONCLUSIONS

The studies summarized in this report examined the effects of installing stormwater treatment BMPs in roadside ditches at eight project sites. Four project sites focused on water quality treatment BMPs and four project sites focused on flow control BMPs. The selected ditches all carry significant amounts of wet season storm flow. During the duration of these studies, no storms produced flows that exceeded the design capacity of the ditch. No flooding or damage to the ditch was observed within the vicinity of the BMPs. BMP installation costs were low and little or no maintenance was required during this two year study. The BMPs provided reductions in stormwater pollutants and exhibited flow control benefits by reducing dry season flows. In addition, the BMPs at all sites reduced the scouring energy from high flows that can lead to erosion and instability of the ditch. The effect of these BMPs was examined on a small scale in this study. Interest has been expressed in expanding a study of flow control BMPs to examine the effects of wide spread installation of these BMPs on receiving waters in watersheds with a long history of hydrologic and stormwater monitoring.

Water quality BMP designs can be effective in attenuating dry seasons flows and reducing suspended solids (measured as TSS or turbidity), along with associated chemical pollutants (total metals and PAH). These BMPs may function better in some ditches than in others. To maximize effectiveness of these BMPs, an understanding of the pollutants present and the treatment needs of a particular ditch should be evaluated before placement of this type of BMP. For example, the BMPs reduced TSS at project sites where upstream scour and, therefore, a source of turbidity, is present.

Flow Control BMPs should be considered for ditch sites where there is a desire to attenuate dry season low flows. They should also be considered for ditches that have high flows or that are scoured to reduce the energy, and hence the erosion potential of high storm flows in those ditches. The flow control BMPs store and pond water, increasing the likelihood that sediment will also be retained by the BMPs. This suggests that these BMPs may also have water quality benefits by detaining pollutants attached to sediment particles. Flow control projects were not evaluated for water quality benefits beyond some monitoring of turbidity at one project site. These preliminary results support the hypothesis that water quality benefits may also accrue at flow control BMP sites.

Further study would be beneficial in determining the applicability of these BMPs for widespread installation. These ditch studies focused on treating sections of ditches with little prior knowledge of pollutant loads and/or storm flow hydrology. Sampling and testing of storm flow in ditches for pollutants prior to BMP installation would increase the certainty that the BMPs would achieve their objectives by targeting ditches that carry a pollutant load that could be effectively addressed by these types of BMPs.

Additional studies that could help determine applicability of these BMPs might include:

- The study results suggest that BMP effectiveness could be increased by extending the BMPs through a longer length of the ditch. This needs to be tested and verified.

- Evaluating the use of these BMPs to treat problem ditches that have obvious signs of scour or turbidity.
- Comparing results of these BMP treatments to the treatment effects of well maintained, fully vegetated ditches might demonstrate the value of retaining vegetation within the ditch as a BMP.
- Extending the study to evaluate the effects of ditch stormwater BMPs on receiving waters. This study focused on treating very short sections of ditch using varying numbers of BMP check dams. There is an active interest in installing and testing the effects of BMP installation in entire ditch networks throughout a watershed.
- Extending the study to evaluate BMP effectiveness over time and/or to determine maintenance needs for optimal BMP performance.

9.1 Water Quality BMPs

This study was implemented to design and install BMPs that would be low cost, low maintenance structures placed directly into existing roadside ditches. The BMPs would utilize existing road rights-of-way to improve stormwater quality or provide flow control. The studies were designed as before/after treatments, generating paired data sets of influent/effluent stormwater chemistry and measurements of field parameters (flow, turbidity, temperature, DO, pH, and conductivity) to assess the BMPs effect on stormwater quality and flow control.

Water quality benefits described in this report were seen as modest decreases in pollutants including TSS, TKN, total metals (arsenic, chromium, copper, lead, nickel, zinc), dissolved metals (copper, lead and zinc), PAHs, and turbidity. Hardness increased after treatment at two project sites; increased hardness is considered to be a water quality benefit. Water quality benefits were achieved by detention, adsorption and filtering of stormwater through a filtration medium (coarse compost) placed directly into a treatment cell within the BMP. It is unclear how much of these benefits are due directly to filtering and/or adsorption and how much is due to the water quality benefits obtained through stormwater detention by the BMP structure itself. The addition of a compost treatment cell inside the rock check dam structure of the BMP increased the stormwater detention. Stormwater detention could provide water quality benefits by decreasing TSS (and TSS related pollutants such as metals and PAH) through settling. In general, the baseline concentrations measured for pollutants, especially metals and PAH were low in stormwater influent.

Limitations. Limitations in the effectiveness of water quality treatment include the amount, or cross-sectional area of compost that could be placed securely in the ditch relative to the volume of stormwater that the ditch carried. For example, ditches at one project site conveyed over a half million gallons of storm flow per day during winter storm events. This limitation was addressed in part by increasing the number of BMP structures placed with in the study area.

In general, stormwater pollutant concentrations measured during these studies were relatively low. The ability to measure treatment effects required untreated stormwater influent with a detectable level of pollutants against which a treatment effect could be measured. These BMP designs would be best utilized by placing them throughout an entire section of ditch, thereby minimizing the opportunities for pollutants and solids to accrue in the storm flow. Increasing the length of the ditch treated by BMPs allowed for increased storm flow input between the influent and effluent monitoring stations which complicates the assessment of BMP effectiveness, since pollutant input could also occur between the monitoring stations.

Uncontrolled variables that affect stormwater flow and pollutant loads include antecedent dry periods, soil saturation, total rain fall (vs. forecasted rainfall) and, more importantly, rainfall intensity. These uncontrolled variables make stormwater sampling a very difficult undertaking and affect both discrete and continuous sampling protocols. Composite sampling evaluates the entire storm event whereas grab sampling can easily miss the parts of the storm with the highest pollutant concentrations. This was amply demonstrated by our experience comparing the results of discrete sampling of turbidity vs. continuous turbidity monitoring. Evaluation of the effect of the BMPs was also limited by the low frequency of the “perfect storm”; numerous storms were sampled that resulted in flows that overtopped the BMPs (and their intended performance level).

9.2 Flow Control BMPs

Flow control benefits described in this report were seen as decreases in dry season effluent flows, particularly from July through September and into early October. This was presumed to occur by increased infiltration during these dry season storms. Typically, wet season flows were higher at effluent monitoring stations due to water inputs between the monitoring stations. However, the BMPs decrease the erosive energy in higher volume storm flows even when the BMPs are overtopped and so some benefits to water quality are also expected from flow control BMPs.

Limitations. The project was successful at monitoring continuous storm flow at all flow control project sites. Limitations in the ability to assess flow control aspects of BMP projects were primarily due to an inability to control watershed inputs along the length of the projects that resulted in higher effluent flows particularly during wet season storms.

Site Suitability. BMPs should be considered for installations in locations that meet the following criteria:

- Ditch sections with known water quality issues such as scour, high pollutant concentrations, ditches that are adjacent to high volume roads, long sections of roadside ditch, and ditch sites that experience high flow conditions.

- Locations where opportunities for other water quality treatment options are limited, such as areas too constrained for treatment ponds.

Lessons Learned.

Lack of a control ditch. The BMP studies described in this report were assessed as a before/after treatment, but the study lacked a control ditch with upstream and downstream monitoring to assess the effects of no BMPs placed in the ditch.

Baseline water quality. While some flow monitoring was done at some project sites, an alternative to a control study would have included collection of baseline or pre-BMP influent and effluent chemistry sample pairs.

Parameter selection. First year studies monitored for dissolved metals but did not include analysis of total metals. Reductions in total metals were seen during second year studies.

Site Selection. The selected sites were representative of the various roadside watershed drainage features found in unincorporated King County, and provided adequate flows for assessing BMP function. However, a more detailed assessment of stormwater conditions in existing ditches is needed to better understand the optimal conditions (location, condition of ditch, flows, etc.) for installation of the BMPs.

FIGURES

TABLES

APPENDICES

Appendix A.
Storm Summary Figures

Appendix B.
Quality Assurance/Quality Control

Appendix C.

Analytical Result Charts

Appendix D.
BMP Plan Drawings

Appendix E.

Photographs

Appendix F.
References